Teacher Pension Systems, the Composition of the Teaching Workforce, and Teacher Quality

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Abstract

Teacher pension systems target retirements within a narrow range of the career cycle by penalizing individuals who separate too soon or remain employed too long. The penalties result in the retention of some teachers who would otherwise choose to leave, and the premature exit of some teachers who would otherwise choose to stay. We examine how the effects of teachers' pension incentives on workforce composition influence teacher quality. Teachers who are held in by the "pull" incentives in the pension systems are not more effective, on average, than the typical teacher. Teachers who are encouraged to exit by the "push" incentives are more effective on average. We conclude that the net effect of teachers' pension incentives on workforce quality is small, but negative. Given the substantial and growing costs of current systems, and the lack of evidence regarding their efficacy, experimentation by traditional and charter schools with alternative retirement benefit structures would be useful.

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I. Introduction

Teacher quality has been consistently identified by researchers as being one of the most important determinants of student success in schools. In their summary of the recent literature, for example, Hanushek and Rivkin (2010) show that a student who moves from the 25th percentile to the 75th percentile in the distribution of teacher quality can be expected to increase her achievement by roughly 0.20 standard deviations of test scores in a single year. This effect size is on par with the effect of a ten-student reduction in class size, and is large relative to race- and income-based achievement gaps.[1] Chetty et al. (2011) further demonstrate that exposure to high-quality teachers in K-12 schools has significant long term effects on matriculation to college, early-career labor market earnings, teen pregnancy, and related consequential outcomes.

The contribution of the present study is to examine how the incentives imbedded in teacher pension systems affect teacher quality through their influence on the composition of the teaching workforce.[2] Teacher pension systems affect workforce composition through their "pull" and "push" incentives. The "pull" incentives arise because pension-wealth accrual is backloaded, which encourages teachers to remain in the profession up to a certain point. The "push" incentives are driven by the fact that pension benefits cannot be collected while working (this is a standard feature of defined-benefit (DB) pension plans). Once a teacher becomes eligible to collect her pension each year of continued work represents a year of forgone pension payments, which means that teachers experience an immediate spike in the opportunity cost of continued work upon becoming benefit eligible. This creates a strong "push" incentive to exit the profession.[3]

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[1] Also see Aaronson et al., 2007; Koedel and Betts, 2011; Nye et al., 2004; Rivkin et al., 2005; and Rockoff, 2004.

[2] Research based on simulated policy changes suggests that adjusting the composition of the teaching workforce can meaningfully affect teacher quality. The policy context in recent studies involves teacher layoffs and/or tenure denials. See, for example, Boyd et al. (2011), Goldhaber and Hansen (2010), Staiger and Rockoff (2010), and Hanushek (2009).

[3] One way to think about the push incentives is in terms of the pension replacement rate. Over the range of the career cycle where the push incentives are strong, teachers who choose to continue working are doing so for pennies on the dollar – that is, their earnings would be similar if they quit working and began collecting their pensions.

Most teachers experience sharp spikes in pension wealth, which quickly shift them from the "pull" to "push" regions of the incentive structure, at relatively young ages (Costrell and Podgursky, 2009). In Missouri, the location of our study, a teacher who enters the profession at age 25 and teaches continuously maximizes her pension wealth at age 56, and thereafter her pension wealth declines with each subsequent year of work. Teachers clearly respond to their retirement incentives. The median retirement age of Missouri teachers is 57, which is similar to the national median of 59 (Ehlert, Ni, Podgursky, 2009). Since teachers are retiring at such early ages with pensions that replace a high fraction of earnings, retirement benefits have become an increasingly expensive part of the teacher benefit package. As states attempt to come to grips with burgeoning retirement costs it is important to examine whether the workforce benefits from these types of compensation schemes justify the cost.

It is uncontroversial that the backloading of pension wealth accrual discourages teacher exits over a portion of the career cycle, which increases retention.[4] It has been argued by some that this feature of teacher pension systems improves workforce quality (Weller, 2011), but we are not aware of any direct evidence to support this hypothesis.[5] Drawing on Lazear (1986), a potential benefit of DB pension plans is that they can raise worker productivity by eliciting effort. The textbook context is one where performance monitoring is imperfect and workers risk losing their pensions by shirking. But this context is a poor fit for teachers because experienced teachers have tenure, which makes the threat of losing a pension not credible.[6] Therefore, rather than affecting effort, it is more likely that the pension systems affect teacher quality by influencing workforce composition. Some

[4] For general evidence on the mobility effects of DB pension plans see Friedberg and Owyang (2005); also see Costrell and Podgursky (2009).
[5] Weller's argument is based on his conclusion that teacher pension systems reduce turnover – he comes to this conclusion through an indirect analysis, but several other studies disagree. We address the turnover issue below.
[6] Lazear (1986) analyzes the efficiency rationale for this type of incentive structure in the context of a competitive firm. A key factor in his model is the role of a pension as a performance bond to discourage shirking. The model also features the divergence of worker productivity and earnings beyond a certain level of experience, hence the need to push workers out of the workforce.

teachers will remain in teaching and some will exit regardless of their pension-related gains or losses. The question of quality centers on teachers at the margin – that is, those whose retirement behaviors are directly influenced by their pension incentives.[7]

We use administrative data from Missouri to examine how the pull and push incentives affect workforce quality. Our empirical strategy is facilitated by the rules of the Missouri system, where teachers experience up to two large, exogenous spikes in pension wealth generated by two different early-retirement provisions over the course of the teaching career. Teachers who exit the system before reaching the first spike in pension wealth incur a substantial financial loss. Teachers who continue teaching beyond the second spike face non-negligible penalties associated with continued work.

We use the Missouri data to divide teachers into groups based in their observed retirement behaviors. We identify three key groups of retirees: (1) *retained teachers*, (2) *typical retirees* and (3) *pushed-out teachers*. Retained teachers are those who are the most likely to have been held in the profession by the "pull" incentives in the pension system. Typical retirees are best viewed as pension wealth maximizers – they work as long as the pension system incentivizes them to do so but quit before the disincentives kick in. Pushed-out teachers continue teaching for several years after the work disincentives take effect. We describe pushed-out teachers as being willing to pay at least modest penalties to remain in teaching, and hypothesize that they would be the most likely to continue teaching beyond their observed exit dates in the absence of their pension incentives.

After identifying these three key groups of teachers based on their retirement behaviors, and several other groups of teachers that we use for comparative purposes, we link teachers to their

[7] This point is also raised by Friedberg and Turner (2010). Goldhaber and Hansen (2010) find that there is considerable overlap in the distributions of teacher quality across experience levels. They show that there are many highly-experienced teachers who do not perform as well as novice teachers in the classroom, which implies that the simple fact that teachers improve with experience is insufficient to draw conclusions about whether it is desirable to retain teachers by backloading compensation.

students in Missouri schools in the year(s) prior to their observed exits. We compare teaching effectiveness across the different teacher types using value-added models. We also compare teachers to their post-exit replacements, which allows us to investigate the extent to which our primary comparisons are biased by unobserved factors related to teachers' schooling environments. We find no evidence to suggest that our main comparisons are biased.

Our results indicate that teachers who exit into retirement, as a group, are more effective than the composite-average teacher in Missouri. But when we split retirees into the key subgroups of interest – retained teachers, typical retirees, and pushed-out teachers – we find that the positive "retiree effect" is driven entirely by pushed-out teachers. This raises the question of whether it makes sense to incentivize these late-exiting teachers to leave the profession. More generally, our findings provide no indication that the substantial resources devoted to targeting educator retirements through teacher pension systems benefit students in K-12 schools. It may be possible to use these resources more strategically to improve workforce quality. A concluding section discusses limitations of our study and, given the very thin literature in this area, ideas for policy experimentation and future research.

II. Pull and Push Incentives in Teacher Pension Systems

Most teacher pension plans are administered at the state level. Different state plans differ in terms of details but share a common structure (Costrell and Podgursky, 2009). The following basic formula is used to determine the annual benefit:

$$B = F * YOS * FAS \tag{1}$$

In (1), B represents the annual benefit, F is a formula factor, which is usually close to two percent (in Missouri, F = 0.025), YOS indicates years of service in the system, and FAS is the teacher's final average salary, commonly calculated as the average of the final few years of earnings. Future benefits may or may not be adjusted for inflation. In Missouri there is an annual inflation adjustment.

It typically takes 3-5 years for teachers to become vested in the system (in Missouri vesting is at five years). Once vested, teachers are eligible to collect a pension upon retirement. The official "normal retirement age" varies across plans and is usually between the ages of 60 and 65. However, an important aspect of all teacher pension plans, and one that is crucial for our work, is that they include generous provisions for early retirement. For example, in Missouri, where the "normal" retirement age is 65, teachers can take advantage of two different early-retirement provisions. The first provision is referred to as "25-and-out". The 25-and-out provision allows teachers to exit and begin collecting benefits immediately, regardless of age, as long as they have 25 years of system experience. There is a modest penalty associated with retirements via 25-and-out, but it is much less than what would be actuarially appropriate. The second provision is referred to as "the rule of 80". The rule of 80 states that whenever a teacher's combination of age and experience sums to 80, she can retire and begin collecting benefits immediately and without penalty. This means, for instance, that a teacher who begins work at age 22 and works continuously would be eligible for full retirement benefits at age 51 with 29 years of experience.

Figure 1 shows the evolution of pension-wealth accrual over time for a representative mid-career teacher in Missouri, currently 37 years old, who began her career at the age of 25.[8] The figure shows that pension wealth accrues very slowly moving into the teacher's 40s, with small single-year gains in pension wealth. However, the option-value of continued work during the 40s is high – if the teacher survives to the 25-and-out clause, the first spike in the figure, there is a substantial payoff in pension wealth. In fact, in the single year of the 25-and-out spike, the present discounted value of the teacher's pension-wealth earnings, discounted to her current age, is roughly $120,000 (in year-2009 dollars). The spike is so dramatic because with fewer than 25 years of experience the teacher

[8] The calculations underlying the figure require several assumptions about the individual's life expectancy, discount rate, wage-growth profile, etc. – these assumptions and other details about the calculations are discussed in Appendix A. Additionally, Appendix Table B.1 shows a brief history of the pension rules in the Missouri system. Figure 1 shows pension-wealth calculations based on the current system rules, which have remained unchanged since 2002.

cannot begin collecting her pension until her combination of age and experience sums to 80. For example, if she were to quit at the age of 48 with 24 years of experience, she could first collect a pension payment under the rule of 80 when she turned 56 years old – eight years later. But by working one additional year and earning her 25th year of experience, she can retire and begin collecting benefits immediately.

A second, smaller spike in pension wealth occurs when the teacher becomes eligible to retire under the rule-of-80 a few years later. Pension wealth increases continuously up to the rule-of-80 year, then jumps $24,000 in that single year because the teacher can collect her full regular pension without penalty. After the rule-of-80 spike, the pension system imposes costs on continued teaching that increase over time because pension payments cannot be collected while working.[9] Initially, the pension-wealth profile is nearly flat beyond the second pension-wealth spike because continued work increases the size of future pension payments by enough to roughly offset the cost of not collecting. But over time, the cost of not collecting overwhelms the gains from continued work.[10]

The uneven pattern of pension-wealth accrual in Missouri, where the marginal pension-wealth returns to work are initially small, then rise very fast, and then flatten out and become negative over the course of the career cycle, is typical of teacher pension systems nationwide (Costrell and Podgursky, 2009). Less typical, although still not uncommon, is the two-spike structure of the Missouri system generated by the two different early-retirement provisions. We exploit the two spikes in the Missouri system to examine how these powerful incentives affect teacher quality.

[9] There is a small third "spike" in the pension system on the downward sloping portion that corresponds to what is effectively a retroactive bonus to teachers who work their 31st year in the system. See Appendix Table B.1 for details.
[10] An alternative way to think about the declining pension wealth for late-career teachers is to think about the pension-system replacement rate. Based on the parameters of the system in Missouri, if the representative teacher in Figure 1 worked through age-60, her annual pension benefit if she chose to retire would be equal to 90 percent of her final average salary (she would have 36 years of service, and the formula factor is 0.025). Factoring in that she would no longer contribute to the pension system (13.5% of salary), she would receive a larger income as a retiree than if she continued teaching.

As noted above, we are primarily interested in the teachers whose behaviors are most likely to have been altered by their pension incentives.

Our empirical approach, which we describe in detail in the next section, requires that the spikes in the pension system are not correlated with other, unobserved career events that affect teacher quality. For example, if teaching effectiveness noticeably changes between the 24^{th} and 25^{th} year of experience, or in the years around when teachers typically reach the rule-of-80 (noting that teachers reach the rule amount with different age-experience combinations), it would make it difficult to identify the pension-system effects on teacher quality. However, these scenarios seem unlikely, and we proceed under the maintained assumption that the timing of the pension-wealth spikes in the Missouri system is (conditionally) uncorrelated with other factors related to teaching effectiveness.

III. Empirical Strategy

We begin with a general model of student achievement designed to distinguish differences in teaching performance across teacher types. Using data where students are linked to teachers at the school-by-grade level we estimate the following model:

$$\begin{aligned} Y_{isgt} &= Y_{isg(t-1)}\gamma_1 + X_{isgt}\gamma_2 + S_{isgt}\gamma_3 + LY_{isgt}\gamma_4 \\ & GC_{isgt}\delta_1 + SC_{isgt}\delta_2 + PE_{isgt}\delta_3 + RT_{isgt}\delta_4 + TR_{isgt}\delta_5 + PO_{isgt}\delta_6 + \\ & + \xi_s + \xi_t + u_{isgt} \end{aligned} \qquad (2)$$

Equation (2) is a typical, unrestricted value-added model of student achievement (Harris and Sass, 2006; Todd and Wolpin, 2003). Y_{isgt} indicates a test score for student *i* at school *s* in grade *g* during year *t;* X_{isgt} is a vector of observable characteristics for student *i*, including race, gender, free-lunch status, language status and mobility status; and S_{isgt} is a vector of school-level characteristics analogous to the student-level information, but measured as building-level compositions for the school attended by student *i* in year *t*. The variable LY_{isgt} indicates the share of teachers in the school-by-grade combination for whom year *t* is their final year of teaching. Our inclusion of this control is motivated by Hansen (2008), who shows that teachers perform worse in the year prior to exiting the profession. ξ_s and ξ_t are school and year fixed effects; we report estimates from models with and without school fixed effects.[11]

The variables of interest are in the second row of the equation: GC_{isgt}, SC_{isgt}, PE_{isgt}, RT_{isgt}, TR_{isgt} and PO_{isgt}. These variables identify teacher types based on their observed exit and mobility behaviors over the course of the data panel. In order, they refer to grade changers, school changers, premature exiters, retained teachers, typical retirees and pushed-out teachers.

Beginning with school and grade changers, a teacher is classified into one of these groups if she is observed changing schools or grades over the course of our data panel. Neither group of mobile teachers is of direct interest in our analysis because neither group is responding to pension incentives. Nonetheless, we capture their effects to retain a comparison group of immobile, non-exiting teachers in some models.

The next four variables identify subgroups of exiting teachers. The first subgroup of exiters, denoted by PE_{isgt}, are premature exiters. Premature exiters are those who retire prior to reaching the first pension-wealth spike in the Missouri system. Because a large fraction of observed exits are premature by this definition (see Section IV), we further divide premature exiters into three groups based on teaching experience at the time of exit: those with 0-4 years of experience, 5-9 years of experience, and 10 or more years of experience.

[11] We exclude school-level covariates from the school-fixed-effects models. The coefficients on the school-level covariates are mechanically identified in the school-fixed-effects models because the covariates vary over time within schools, but it is not clear that the identifying variation is useful in the school-fixed-effects models. For completeness we also estimated school-fixed-effects models that include the school covariates (results omitted for brevity), and our findings are nearly identical to what we report below.

The next group of exiting teachers are retained teachers, denoted by RT_{isgt}. We define retained teachers as those who exit within one year of reaching the first pension-wealth spike in the Missouri system but prior to becoming eligible for full retirement under the rule of 80.[12] We hypothesize that retained teachers are the most likely to have been retained by the pension system up to the point of their observed exits.

The third group of exiting teachers, denoted by TR_{isgt}, are teachers who we identify as typical retirees. For the purposes of our analysis, a "typical" retirement occurs when the teacher does not exit until she is eligible to collect under the rule of 80, but does exit within three years of attaining eligibility. Prior research shows that a large fraction of teachers exit within the first few years of becoming eligible for full retirement (Podgursky and Ehlert, 2007).

Finally, the fourth group of exiting teachers consists of "pushed-out" teachers, denoted by PO_{isgt}. We define pushed-out teachers as those who work for more than three years after becoming eligible for benefit collection under the rule of 80, and are observed exiting at some point during the data panel. These are individuals willing to incur at least modest pension-wealth penalties to continue teaching. We hypothesize that they would teach even longer in the absence of their pension disincentives.

The mobility and exit variables are coded as the percentages of teachers in each school-by-grade-by-year combination who are classified in each group. The teacher types are defined statically – for example, if a teacher is observed exiting the profession as a pushed-out teacher in the fourth year of our data panel, she is coded as a pushed-out teacher in each year that she teaches. In our main models we create exclusive categories of teachers by forming a hierarchy for the classifications

[12] We include teachers with 25 or 26 year of experience in this group to increase our sample size. If we rigidly define retained teachers as those who exit with exactly 25 years of experience we get similar, noisier results. In a robustness test below we also include teachers who exit with 24 years of experience in the "retained" group, which would be reasonable if these teachers actually reached 25-and-out but there is measurement error in data.

that runs from left to right in the second row of equation (2). For example, a grade changer who also changes schools is coded as a school changer, a school changer who ultimately exits prematurely is a premature exiter, etc. In unreported results we verify that our findings are not sensitive to creating non-exclusive categories for teachers.

Table 1 summarizes the teacher classifications that correspond to the exit variables. The omitted group in the full model includes teachers who remained in the same school-and-grade combination throughout the data panel. This group is essentially a composite average of the teaching workforce. We estimate the model without including any controls for observable teacher characteristics, including experience, so that the omitted group maintains this interpretation (as opposed to, say, comparing retirees to other experienced teachers). We are interested in two key questions. First, how do retirees *as a group* compare in terms of teaching effectiveness to stable and other exiting teachers? This is an interesting policy question because teacher pension systems create large and expensive incentives to concentrate retirements at certain points in educators' careers, and at young ages relative to retirements in other professions. Thus, it is interesting to see how retirees compare to their not-yet-retired colleagues. Second, we are interested in separating the effects of the pull/push incentives imbedded in the current pension structure. Here we evaluate the effectiveness of the different groups of retirees relative to each other. Is it valuable to push out late-exiting teachers? To hold in retained teachers? It is useful to separately identify the effects of the different retiree types because it is possible to modify the pension structure to eliminate or moderate the retirement incentives as desired.[13]

IV. Data

We use administrative panel data from the state of Missouri for our analysis. Test score data

[13] For example, teachers could be moved to "constant accrual" plans, like DC or cash-balance plans (cash-balance plans are appealing in that they retain the annuity-based payment structure). Smaller changes are also possible. For example, the push out effect could be neutralized by permitting teachers to participate in DROP plans, which allow teachers to collect a pension and continue working.

in math and communication arts (reading) are available for students over a 5-year span: from the 2005-2006 through 2009-2010 school years. We standardize all test scores by subject, grade and year. Data on teachers' school-by-grade assignments are available for the same years, and for several years prior to 2005-2006. Students and teachers are linked at the school-by-grade level throughout the data panel, and classroom links are available for the last two years (2008-2009 and 2009-2010). We estimate our primary models using the full data panel and also report estimates from classroom-linked models for the years where we can perform the analysis. In the classroom-linked models we replace the school-by-grade share variables in equation (2) with direct information about students' actual teacher assignments. Our evaluation focuses on elementary teachers in self-contained classrooms in grades four, five and six.[14] Basic descriptive statistics for the dataset are provided in Table 2.[15]

The data include information about student race, gender, free-lunch status, language status and mobility status. We aggregate the student-level information to the building level to construct measures of school compositions. As discussed above, and shown in Table 1, we use information about teachers' age-experience combinations to divide observed exits from teaching into the different exit categories. Our main regression model in (2) requires data from multiple time periods for each year-cohort of students – we use year t information about students, schools and teachers; year $(t-1)$ information about student test scores; and information from at least one future year to categorize teachers based on their mobility and exit behaviors. The first year of our data panel, 2005-2006, is used only to recover lagged test scores for students in the 2006-2007 cohort. We use personnel data available through 2010-2011 to identify teachers' exit and mobility types. Therefore,

[14] We cannot use data from earlier grades because no pre-test is available for students. We cannot use data from later grades because teacher assignments are not grade specific in later grades – for example, a middle-school math teacher is likely to teach students in multiple grades.

[15] We exclude students and teachers from Kansas City and St. Louis from our analysis because the two urban districts operate their own pension systems. Both of the urban-district pension systems have different parameters, with a key difference being that both are characterized by a single pension-wealth spike. Less than 10 percent of the teachers and students in Missouri are excluded from our analysis because they are in Kansas City or St. Louis.

in total, our five-year achievement data panel facilitates the analysis of four year-cohorts of students: 2006-2007, 2007-2008, 2008-2009 and 2009-2010. The estimation sample available for the model in (2) from these four cohorts includes data from 298,920 unique students taught by 14,619 unique teachers.

V. Results

Tables 3 and 4 show the estimated effects of movers and exiters on student achievement in math and reading, respectively.[16] The first three columns in each table show results from models without school fixed effects; the last three columns show models where school fixed effects are included. Within each modeling structure we vary the omitted comparison group. We first compare all retirees (retained, typical, pushed-out) to all other teachers, then separately estimate the effects of the different retiree types, then additionally include the other types of exiters and movers. As we adjust the comparison groups we observe very modest changes to our estimates for the different retiree groups relative to the omitted category. This is because most teachers are "stable" over the course of the data panel so the omitted comparison group changes little moving from one specification to the next (see Table 2). We also show the coefficient on the last-year-of-work indicator in each model, which estimates the average effectiveness across all exiters in the year prior to their actual exits. Our estimates are consistent with what is reported by Hansen (2008) – teaching effectiveness declines in the year immediately preceding teacher exits.[17]

Recall that the move/exit variables are constructed as the shares of teachers in each school-by-grade combination who move or exit by category. Therefore, the coefficients in the tables should be interpreted as showing the effect of going from a 0 to 100 percent share (note that for the

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[16] Estimates for the other coefficients from the main models are reported in Appendix Table B.2.

[17] There are several other interesting findings in Tables 3 and 4 that we do not highlight in our main discussion. For example, mobile teachers (across schools or grades) perform worse than typical retirees or the average teacher in the omitted group (these findings are consistent with Ost (2010) and Ronfeldt et al. (2011)), and premature exiters are less effective as well (particularly in the reading models).

purpose of interpreting the estimates, the variables are on a 0-1 scale as reported in Table 2).[18] We expect less bias in the estimates when we include school fixed effects because the identifying variation comes from differences in teacher compositions across grades within the same school. However, as a practical matter all of the models produce similar results. We report p-values from statistical tests that compare the effects between retained teachers, typical retirees, and pushed-out teachers where relevant in the tables.

A clearly positive "retiree effect" can be seen in columns (1) and (4) of the tables – retirees are more effective as a group than the composite-average teacher in Missouri. In columns (2) and (5) we divide retirees into the three subgroups. These models reveal that the total retiree effect is driven almost entirely by the fact that pushed out teachers are particularly effective. Typical retirees, on the other hand, are indistinguishable from the composite-average teacher in all of the models. The retained-teacher point estimates are similar to those for pushed out teachers in math, but not in reading, and are noisily estimated; regardless, there are so few retained teachers that they have limited influence over the total retiree effect (see Table 2). Finally, in columns (3) and (6) the retiree effects are moderated to some extent as we remove the other groups of mobile and exiting teachers from the omitted comparison group, although the effect ordering for the different retiree types is unchanged.

How do our findings in Tables 3 and 4 translate into implications for workforce composition? With regard to the "pull" incentives, we find no evidence to suggest that the pension system in Missouri improves workforce quality. Although our estimates are too imprecise to say much about retained teachers, there are so few teachers that are retained in the strict sense of our definition that these teachers are inconsequential. Typical retirees, who are indistinguishable from the composite-average teacher in Missouri despite being more experienced, are both "pulled" and

[18] In many schools there are just one or two teachers per grade, so this is not unreasonable.

"pushed" in the sense that they comply with the pension plan's retirement target. Given that typical retirees perform similarly to other Missouri teachers, the influence of the pension system on typical retirees does not affect teacher quality overall. If the incentives were relaxed some typical retirees would likely quit earlier and others later. Workforce quality would be unaffected.

Alternatively, our findings suggest that the push incentives adversely affect workforce quality. Pushed-out teachers are more effective than the composite-average teacher, which is perhaps not surprising given that they are self-selecting into extended teaching careers. An obvious question that comes from our analysis is whether it makes sense to incentivize these late-exiting teachers to leave the profession. To provide some context for the power of the push incentives that these teachers face, note that a typical pushed-out teacher as defined in our main analysis could easily exit teaching with a pension that replaces 80 percent of her income (based on her highest three years of earnings). Furthermore, she would no longer be required to contribute to the pension plan, which would save an additional 13.5 percent of earnings. Her effective replacement rate, then, would exceed 90 percent. Put differently, her real compensation for continued work would amount to pennies on the dollar. The push incentives are strong, and discourage what appear to be a particularly effective group of teachers from extending their careers in the classroom.

VI. Robustness and Other Estimation Issues

Sensitivity Analysis

We begin by considering the robustness of our findings to adjustments to the definitions of the retiree groups. First, we re-define retained teachers as having 24, 25 or 26 years of experience without reaching the rule of 80. This definition assumes that individuals who are observed to exit with 24 years of experience, and prior to reaching the rule of 80, represent measurement error in the data. A notable source of measurement error is that in some instances teachers can buy years of service toward retirement, which can be particularly lucrative near the pension-system spikes. Bought service years are not recorded in the data.

We also adjust the definition of pushed out teachers by differentially categorizing teachers who are observed working well beyond their rule-of-80 year. Under our definition in Table 1, all teachers who work for more than three years after their rule-of-80 year are defined as pushed out (as long as they are observed exiting over the course of the data panel). However, one could argue that particularly late-exiting teachers are unresponsive to their pension incentives, in which case it would be inappropriate to attribute their behaviors to the pension system. With this in mind, we alternatively define pushed-out teachers as those who work for between 4 and 7 years after reaching the rule of 80. That is, we remove particularly late-exiting teachers from the "pushed-out" group.[19]

Table 5 reports results using the new teacher definitions.[20] For brevity we only report estimates from the model with the retirement-group indicators, and with school fixed effects (as in column (5) of Tables 3 and 4). The estimates in Table 5 are consistent with our main results. We conclude that our findings are robust to reasonable adjustments to the definitions of the retiree groups.

Next we consider the robustness of our findings to models that link students and teachers at the classroom level. Recall from the previous section that we have access to classroom-linked data for two years: 2008-2009 and 2009-2010. Table 6 reports estimates from models analogous to the model in equation (2), but estimated using the classroom links. The key difference in the classroom-linked models is that we include direct information about teachers based on students' actual teacher

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[19] These late-exiting teachers are essentially working for free. They may view teaching as leisure, or alternatively, they may not understand their pension incentives (Chan and Stevens, 2008; Gustman and Steinmeier, 2004).

[20] Minor adjustments to the other exiting groups are made to facilitate the adjusted definitions for retained and pushed-out teachers where appropriate. For example, when we modify our definition of "retained" teachers to include individuals with 24 years of experience at the time of the observed exit, we adjust the "premature 3" group to exclude these individuals.

assignments.[21] The results in Table 6 are similar to our previously reported findings but suggest smaller differences between retiree groups (more so in reading than in math).

Sources of Bias

We have shown that our findings are robust to changing the way that students are linked to teachers, and to adjusting the definitions for retirees. But the general concern remains in all of the previous models that unobserved differences in the schooling environments for teachers could contribute to the retirement behaviors that we observe, and to student achievement, which would make the retirement variables endogenous. As a specific example, it could be that teachers who stay in the profession longer than is typical, who we categorize as "pushed-out," do so partly because of favorable working conditions that are positively related to student achievement and poorly proxied by the controls in our models. Similarly, retained teachers might exit immediately upon becoming benefit-eligible because their working conditions are unfavorable. If our models do a poor job of controlling for the relevant aspects of the schooling environments for teachers, then our estimates may not reflect true differences in teaching performance between retirees and non-retirees, and across retiree groups.

Two aspects of our analysis suggest that any bias from unobserved factors related to schooling environments will be small. First, the exit variables in our main models are aggregated to the school-by-grade level. An advantage of aggregating the data to this level is that our estimates will not be biased by student-teacher sorting within grades.[22] Second, our richest models include thorough sets of student- and school-level covariates, including lagged test scores for students, and

[21] Note that the differences between our findings in Tables 3 and 4, and Table 6, are not related to differences between treatment and intention-to-treat effects. Both tables report treatment effects owing to the fact that we use school-by-grade shares as independent variables in equation (2). The estimates from equation (2) would be interpretable, loosely speaking, as intention-to-treat estimates if we used dummy variables to indicate the presence of certain types of teachers in each school-by-grade combination rather than the percentages.

[22] A comparison of our estimates using the classroom and school-by-grade links also suggests that issues related to student-teacher sorting are unlikely to be causing large bias in our estimates. The general issue of student-teacher sorting within schools and grades, and its implications for value-added modeling, has received much attention in recent research. See Chetty et al. (2011), Goldhaber and Chaplin (2011), Koedel and Betts (2011), Rothstein (2010).

school fixed effects. In the models that include school fixed effects, any bias from differences in the favorability of schooling environments across exiters must come from within-school/across-grade differences, which are plausibly small.

Although the potential for bias in our estimates seems limited, we nonetheless perform a secondary regression analysis to directly address the bias concern. The secondary model evaluates teaching performance in the school-by-grade combinations where retirements and turnovers are observed, but in the years *after they actually occur*. That is, it measures the effectiveness of the teachers who replace the exiting teachers from the primary models.[23] Conditional on the other controls in the models, and in particular the school fixed effects, our expectation is that regardless of why a turnover occurs, the replacement teacher(s) should, on average, be similarly effective.

Consider the following secondary regression:

$$Y_{isgt} = Y_{isg(t-1)}\beta_1 + X_{isgt}\beta_2 + S_{isgt}\beta_3 + GC_{isgt}^{t-1}\theta_1 + SC_{isgt}^{t-1}\theta_2 + PE_{isgt}^{t-1}\theta_3 + RT_{isgt}^{t-1}\theta_4 + TR_{isgt}^{t-1}\theta_5 + PO_{isgt}^{t-1}\theta_6 + \phi_s + \phi_t + e_{isgt} \quad (3)$$

Equation (3) is analogous to equation (2) except that the retirement-group variables take on a different meaning. Specifically, as denoted by the superscripts, they indicate the share of the teaching workforce in each school-by-grade combination *that was replaced from the prior year*, by category. So, for example, if there were four teachers in school-by-grade combination X in year *(t-1)*, and a single teacher exited as a pushed out teacher, PO_{isgt}^{t-1} would be equal to 0.25.[24]

The model in (3) can be used to test for differences in effectiveness across the teachers who replaced the exiting teachers from the main analysis. One way that such differences might emerge is

[23] Or, in the case where no replacement teacher enters, the new model evaluates the performance of the remaining teachers in the same school-by-grade combinations where the exit or move occurred.

[24] The structure of equation (3) facilitates the inclusion of one extra year-cohort of students in the models. The reason is that we do not need to identify retirement behaviors for teachers beyond year-t in equation (3). If our personnel files did not predate the student achievement data (first gainscore available in 2006-2007), the model in (3) would be estimated on a shifted dataset but the number of year-cohorts would not change; however, the personnel data extend back into the 1990s, which facilitates our inclusion of the extra year-cohort of data for estimation. We also note that we have estimated equation (3) using several different partitions of the data, and our results are always substantively similar.

if there are unobserved differences in the work environments from which the different groups of exiting teachers left in the prior year. The null hypothesis that we test is $H_0 : \theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = \theta_6$. A failure to reject this hypothesis would be consistent with the scope for bias from unobserved confounders in our models being small.

Our results are reported in Table 7. The negative values for the turnover coefficients throughout the table reflect the fact that in any instance where a turnover variable is non-zero, students are moving into a situation where there was a disruption to the teaching staff (the negative coefficients taken together are in line with recent findings from Ronfeldt et al., 2011). The null hypothesis of equality between the exit and mobility coefficients cannot be rejected except in the reading model with school fixed effects, where the p-value is marginally significant. The p-values for the equality tests between the three retiree-turnover coefficients are large in all specifications, and none are close to the rejection range.

While the formal tests in Table 7 do not signal significant bias in our main results, the point estimates are at least suggestive of modest differences in performance across teachers who replace the different types of exiters and retirees. If we take the differences in the point estimates in Table 7 at face value, and treat them entirely as evidence of bias in our main models (Tables 3 and 4), this would suggest that the retiree groups are less effective overall. One implication is that pushed-out teachers would no longer appear to be clearly more effective, on average, than typical retirees or the composite average teacher. However, even if we take this strong interpretation of the estimates in Table 7, there is still no evidence to suggest that the substantial resources devoted to targeting educator retirements through teacher pension systems are an effective workforce strategy.

Misclassification Error

Finally, we briefly note that the way that we define exits and retirements likely causes some misclassification error. There are two misclassification issues that merit attention. First, some teacher exits are unplanned. As an example, consider an exit that occurs because of an unexpected medical event immediately after a teacher attains her 25th year of service. We would interpret the exit as evidence that the teacher belongs to the "retained" group; but she may be very different from the typical teacher who *plans* to exit immediately after reaching her 25th year of service. Similarly, happenstance teacher exits that coincide with any of the exit definitions will lead to teacher misclassifications. Misclassification errors along these lines will attenuate differences in teaching performance across the exiter subgroups, although we expect these types of errors to be uncommon.

Another source of misclassification error comes from how we identify exits using the data. Specifically, we identify exits based on whether teachers re-appear in the data panel in future year(s). So, for example, a "typical retiree" is defined as such if she is observed teaching up until she reaches the rule-of-80, and then is no longer observed in the data panel. To maximize the use of available data a teacher can be classified into an exit category based on as little as a single year of information looking forward; extending the previous example, the typical retiree in question may have worked up through 2009-2010 and not shown up in the 2010-2011 data to earn her designation. But the possibility that she reappears in 2011-2012 – which is beyond our data panel – cannot be precluded. We examine the prevalence of misclassification errors along these lines in Appendix B. In brief, while misclassification errors do occur they are rare, particularly for teachers who are classified as exiting into retirement. Put differently, while some early-career exiters are misclassified because they leave and come back, late-career teachers rarely move in and out of the data panel. We conclude that attenuation bias from misclassification errors along these lines will be small.

VII. Additional Considerations

Initial Selection into Teaching

A limitation of our analysis is that it conditions on individuals who initially select into teaching. If the structure of teacher pension systems affects the initial entry decision, which seems likely given the substantial fraction of compensation that pension benefits represent for teachers (Costrell, 2011), this should also be incorporated into a broader evaluation of the compositional effects of the pension systems. Unfortunately, we do not have the data to empirically evaluate the effect of the pension system in Missouri on initial selection.

That said, heavily backloaded teacher pension plans would not seem to be a particularly effective recruiting tool for high-quality young teachers. One reason is that the pension structure penalizes mobility, and Groes et. al. (2010) show that across the top 80 percent of the ability spectrum, job mobility is positively related to general ability and productivity. If higher ability individuals place higher *ex ante* probabilities on exits from teaching, as evidence suggests they do (e.g., Murnane and Olsen, 1990; Podgursky, Monroe, and Watson, 2004), then the backloaded structure of pension-wealth accrual will be unattractive. Thus, we would not expect a DB pension to entice entry among high-ability individuals, especially when compared to more mobile retirement benefits such as 401k plans, or simply higher salaries.

Teacher Turnover

Even if the pension incentives have a neutral effect on workforce quality through their effects on the pattern of exits, it is still possible that they could affect workforce quality by affecting the overall level of turnover. In a steady state, higher teacher turnover would mean more novice teachers in the workforce. Because novice teachers are less effective on average, this would mean a lower level of workforce quality. This leads to arguments along the lines of those by Weller (2011), who postulates that teacher pension systems raise workforce quality by lowering teacher turnover.[25]

We are not aware of any direct evidence on how teacher pensions affect turnover (one reason is that we are not aware of an observed counterfactual – that is, a large group of teachers who

[25] Weller's claim is based on general labor market studies comparing workers with and without pensions. However, the "no pension" condition does not seem to be the relevant counterfactual. More relevant would be fiscally equivalent compensation schemes with: a) higher salaries and less generous pensions, and/or b) less backloaded pensions like defined contribution, cash balance, or "hybrid" mixes of DB and DC.

are not enrolled in a DB pension plan). Some of the best indirect evidence comes from Harris and Adams (2007), who compare job mobility in teaching and several other professions over the course of the career cycle (nursing, social work, accounting). They show that job mobility for teachers is similar to mobility in other professions, with the exception that exits from the labor force among teachers begin at earlier ages. Their analysis suggests a minimal role for the retention effects of teacher pension systems and a larger role for the push-out effects, with the net result being higher turnover.

Costrell and McGee (2010) also evaluate pension-system effects on turnover indirectly and reach a similar conclusion. They estimate a model of Arkansas teacher exits as a function of pension wealth accrual, and use the model to simulate the effect of a fiscally equivalent "cash balance" plan that has smooth wealth accrual and no push or pull incentives. They find that the transition to such a plan would modestly increase average teacher tenure.

However, while both of these studies are suggestive, direct evidence is unavailable. The primary difficulty in obtaining direct evidence on the turnover question is the absence of variation in policy alternatives (e.g., some schools with DB plans and others with alternative plans). This is an important issue for future research and policy consideration.[26]

District Fiscal Savings

A common argument made for the strong push-out incentives in teacher pension systems is that they produce savings for school districts as higher-salaried senior teachers are replaced by less-expensive new teachers. Indeed, in addition to the early retirement incentives built into most state plans, one routinely sees language in teacher collective bargaining agreements providing incentives, either in lump sum payments or salary increases, to educators who pre-commit to retire by a certain

[26] One interesting potential source of policy variation is charter schools. In sixteen states charter schools can opt out of state teacher pension plans and set up their own plans, and many have chosen to do so. There has been almost no research on the charter school experience in this area (Olberg and Podgursky, 2011).

date. Examination of these fiscal effects is beyond the scope of this study. However, we note that these purported cost savings may not be efficiency-enhancing. First, using expensive pension incentives to offset the tilt in the salary schedule may produce short term fiscal savings for the district, but the net fiscal savings may be negligible or even negative if the early retirements in a particular district simply increase unfunded liabilities of the pension system as a whole. More basic, however, is the question as to why the district has chosen to tilt the salary schedule at all. If the productivity of the senior teachers does not justify their higher pay, then why is it present? Lazear (1986) and others have argued that backloading of pay and benefits may be justified when there are specific training costs or monitoring problems. However, for reasons noted earlier, these issues do not seem relevant for public sector teachers.

VIII. Discussion and Conclusion

We examine the link between the pull and push incentives in teacher pension systems and teacher quality using longitudinal micro data for Missouri. We find that the "pull" incentives neither raise nor lower teacher quality, and the "push" incentives modestly lower teacher quality by discouraging effective teachers from extending their careers. The implication is that the net effect of teacher pension systems on workforce quality is small and negative.

The backloading of wealth accrual in teacher pension systems produces large penalties for mobile teachers and substantially redistributes pension wealth away from short-spell teachers (Costrell and Podgursky, 2010). Given that alternative compensation schedules may affect the composition of the teaching workforce in positive ways, most notably by favorably influencing initial selection into the profession, experiments with systems that are more equitable for short-term or mobile teachers, or even front-loaded, merit consideration in lieu of the current structure of lucrative, but distant, defined benefits (Vigdor, 2008). TIAA-CREF serves as one example and is used in much of higher education; and in states where it is permitted, many charter schools have begun to implement their own defined contribution (DC) plans (Olberg and Podgursky, 2011). A DC-type mobile benefit (or simply higher starting salaries and fewer deferred benefits) may serve as an attractive tool for shortage-area teachers (e.g., those in STEM fields) – particularly if these individuals are not ready to commit at a young age to a full career in education. At the other end of teaching careers, one could easily imagine DROP or other retirement reemployment options that are only open to highly effective teachers. In short, teacher retirement plans, and the revenues devoted to them, might be used in more strategic ways to improve the quality of the teaching workforce.

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Figure 1. Pension wealth accrual over the career cycle for a representative teacher in Missouri who began her career at the age of 25 and is currently 37 years old. Two spikes in pension-wealth corresponding to the early-retirement provisions are marked.

Table 1. Definitions for Groups of Exiting Teachers.

Teacher Group	Definition
Premature Exits 1 (PE_{isgt}^{t+1})	(Age + Experience) < 80, Experience < 5
Premature Exits 2 (PE_{isgt}^{t+1})	(Age + Experience) < 80, 5 ≤ Experience < 10
Premature Exits 3 (PE_{isgt}^{t+1})	(Age + Experience) < 80, 10 ≤ Experience < 25
Retained Teachers (RT_{isgt}^{t+1})	(Age + Experience) < 80, Experience = 25 or 26
Typical Retirees (TR_{isgt}^{t+1})	80 ≤ (Age + Experience) ≤ 85
Pushed-Out Teachers (PO_{isgt}^{t+1})	(Age + Experience) > 85

Note: There is a very small group of teachers who retire several years after reaching the 25-and-out provision, but before reaching the rule of 80, who are missed by the categorizations listed here. For completeness we control for these teachers as a separate group in the models, which allows us to retain our well-defined comparison groups. The parameter estimate corresponding to this group of teachers is estimated very imprecisely and is not of independent interest.

Table 2. Data Details.

Data for Primary Model, Full Panel (Equation 2):		
Schools	1,099	
School-by-grade combinations	2,321	
Unique teachers	14,619	
Unique students	298,920	
Total student test-score-gain records	451,948 (math) / 450,986 (com arts)	
Fraction of test-score records that are dropped because a lagged score is unavailable for the student	5.28% (math) / 5.30% (com arts)	
School-by-grade average shares of teachers classified as:		
School changers	0.067	(range: 0 – 1)
Grade changers	0.127	(range: 0 – 1)
Exiters – premature 1	0.094	(range: 0 – 1)
Exiters – premature 2	0.063	(range: 0 – 1)
Exiters – premature 3	0.063	(range: 0 – 1)
Retained teachers	0.003	(range: 0 – 1)
Typical retirees	0.029	(range: 0 – 1)
Pushed out teachers	0.025	(range: 0 – 1)

Table 3. Teacher Performance by Exit and Move Categories. Exit and Move Variables are Measured as Percentages of Teachers in Each School-by-Grade Combination. Math Models.

Exit Category						
School Changer	--	--	-0.014	--	--	-0.042
			(0.016)			(0.017)*
Grade Changer	--	--	-0.023	--	--	-0.033
			(0.012)†			(0.014)*
Premature Exit 1	--	--	-0.007	--	--	-0.026
			(0.017)			(0.018)
Premature Exit 2	--	--	0.013	--	--	-0.008
			(0.019)			(0.020)
Premature Exit 3	--	--	0.001	--	--	-0.015
			(0.019)			(0.021)
All Retired	0.043	--	--	0.049	--	--
	(0.017)**			(0.018)**		
Strictly Retained	--	0.082	0.078	--	0.076	0.058
		(0.087)	(0.087)		(0.089)	(0.089)
Typical Retiree	--	0.017	0.014	--	0.039	0.022
		(0.023)	(0.023)		(0.025)	(0.027)
Pushed Out	--	0.069	0.065	--	0.058	0.044
		(0.025)**	(0.026)*		(0.025)*	(0.026)†
In Final Year of Work	-0.040	-0.040	-0.045	-0.046	-0.046	-0.042
	(0.012)**	(0.012)**	(0.015)**	(0.011)**	(0.011)**	(0.014)**
Retiree Comparisons (p-values)						
H_0: Retained=Typical	--	0.47	0.48	--	0.69	0.70
H_0: Pushed-Out=Typical	--	0.11	0.12	--	0.58	0.53
H_0: Retained=Pushed-Out	--	0.89	0.89	--	0.84	0.87
Student Covariates	X	X	X	X	X	X
School Covariates	X	X	X			
School Fixed Effects				X	X	X
R-Squared	0.64	0.64	0.64	0.65	0.65	0.65
N	451,948	451,948	451,948	451,948	451,948	451,948

Notes: Standard errors are in parentheses and clustered at the school-by-grade-by-year level. The "In Final Year of Work" effect is estimated using all teachers in the data observed exiting in the following year.
** Indicates statistical significance at the 1 percent level.
* Indicates statistical significance at the 5 percent level.
† Indicates statistical significance at the 10 percent level.

Table 4. Teacher Performance by Exit and Move Categories. Exit and Move Variables are Measured as Percentages of Teachers in Each School-by-Grade Combination. Reading Models.

Exit Category						
School Changer	--	--	-0.006	--	--	-0.035
			(0.012)			(0.013)**
Grade Changer	--	--	0.005	--	--	-0.026
			(0.009)			(0.011)*
Premature Exit 1	--	--	-0.016	--	--	-0.039
			(0.012)			(0.013)**
Premature Exit 2	--	--	-0.000	--	--	-0.026
			(0.014)			(0.015)†
Premature Exit 3	--	--	0.006	--	--	-0.019
			(0.014)			(0.016)
All Retired	0.031	--	--	0.036	--	--
	(0.013)*			(0.014)*		
Strictly Retained	--	-0.029	-0.035	--	0.015	-0.008
		(0.065)	(0.065)		(0.061)	(0.062)
Typical Retiree	--	0.014	0.011	--	0.010	-0.012
		(0.018)	(0.018)		(0.020)	(0.021)
Pushed Out	--	0.057	0.055	--	0.069	0.051
		(0.020)**	(0.020)**		(0.020)**	(0.021)*
In Final Year of Work	-0.029	-0.029	-0.023	-0.026	-0.026	-0.013
	(0.009)**	(0.009)**	(0.012)*	(0.009)**	(0.009)**	(0.011)
Retiree Comparisons (p-values)						
H_0: Retained=Typical	--	0.52	0.49	--	0.93	0.95
H_0: Pushed-Out=Typical	--	0.10	0.09	--	0.03	0.02
H_0: Retained=Pushed-Out	--	0.21	0.18	--	0.41	0.36
Student Covariates	X	X	X	X	X	X
School Covariates	X	X	X			
School Fixed Effects				X	X	X
R-Squared	0.63	0.63	0.63	0.63	0.63	0.63
N	450,986	450,986	450,986	450,986	450,986	450,986

Notes: Standard errors are in parentheses and clustered at the school-by-grade-by-year level. The "In Final Year of Work" effect is estimated using all teachers in the data observed exiting in the following year.
** Indicates statistical significance at the 1 percent level.
* Indicates statistical significance at the 5 percent level.
† Indicates statistical significance at the 10 percent level.

Table 5. Robustness of Findings to Alternative Definitions for Retirees.

	Math	Reading
Exit Category		
Strictly Retained	0.120	-0.011
	(0.070)†	(0.047)
Typical Retiree	0.039	0.009
	(0.025)	(0.020)
Pushed Out	0.081	0.082
	(0.028)**	(0.024)**
Residual Late Exits	-0.013	0.022
	(0.045)	(0.041)
In Final Year of Work	-0.047	-0.026
	(0.011)**	(0.009)**
Retiree Comparisons (p-values)		
H_0: Retained=Typical	0.28	0.69
H_0: Pushed-Out=Typical	0.26	0.02
H_0: Retained=Pushed-Out	0.59	0.07
Student Covariates	X	X
School Covariates		
School Fixed Effects	X	X
R-Squared	0.65	0.63
N	451,948	450,986

Notes: Standard errors are in parentheses and clustered at the school-by-grade-by-year level. The "In Final Year of Work" effect is estimated using all teachers in the data observed exiting in the following year.
Retained redefined as: exit occurs when experience = 24, 25 or 26 and (age+experience) < 80
Pushed-Out redefined as: exit occurs 4-7 years after reaching the rule of 80
Residual Late Exit: exit occurs later than for pushed-out teachers based on updated definition.
** Indicates statistical significance at the 1 percent level.
* Indicates statistical significance at the 5 percent level.
† Indicates statistical significance at the 10 percent level.

Table 6. Robustness of Findings to Using Classroom Links. Exit Variables are Defined for Students' Actual Teachers for 2008-2009 and 2009-2010 School Years.

	Math		Reading	
Exit Category				
Strictly Retained	0.016	-0.001	-0.004	-0.022
	(0.043)	(0.047)	(0.045)	(0.047)
Typical Retiree	0.023	0.023	0.008	0.002
	(0.019)	(0.018)	(0.017)	(0.017)
Pushed Out	0.040	0.032	0.037	0.035
	(0.020)*	(0.018)†	(0.017)*	(0.015)*
In Final Year of Work	-0.036	-0.037	-0.028	-0.027
	(0.008)**	(0.007)**	(0.006)**	(0.006)**
Retiree Comparisons (p-values)				
H_0: Retained=Typical	0.89	0.64	0.79	0.62
H_0: Pushed-Out=Typical	0.51	0.71	0.21	0.14
H_0: Retained=Pushed-Out	0.61	0.51	0.38	0.24
Student Covariates	X	X	X	X
School Covariates	X		X	
School Fixed Effects		X		X
R-Squared	0.64	0.65	0.62	0.62
N	198,432	198,432	198,043	198,043

Notes: Standard errors are in parentheses and clustered at the school-by-grade-by-year level. The "In Final Year of Work" effect is estimated using all teachers in the data observed exiting in the following year.
** Indicates statistical significance at the 1 percent level.
* Indicates statistical significance at the 5 percent level.
† Indicates statistical significance at the 10 percent level.

Table 7. Teacher Performance in School-by-Grade Combinations that Experience Turnover(s) by Category, in the Year After the Turnover(s).

	Math		Reading	
Exit Category				
School Changer	-0.063	-0.093	-0.050	-0.060
	(0.027)*	(0.024)**	(0.019)**	(0.018)**
Grade Changer	-0.041	-0.042	-0.030	-0.041
	(0.021)*	(0.019)*	(0.015)*	(0.014)**
Premature Exit 1	-0.045	-0.057	-0.037	-0.034
	(0.015)**	(0.014)**	(0.012)**	(0.011)**
Premature Exit 2	-0.064	-0.084	-0.048	-0.059
	(0.021)**	(0.019)**	(0.016)**	(0.015)**
Premature Exit 3	-0.089	-0.099	-0.074	-0.078
	(0.021)**	(0.019)**	(0.016)**	(0.015)**
Strictly Retained	-0.053	-0.042	-0.023	0.028
	(0.093)	(0.077)	(0.072)	(0.052)
Typical Retiree	-0.066	-0.060	-0.028	-0.030
	(0.029)*	(0.027)*	(0.021)	(0.020)
Pushed Out	-0.026	-0.029	-0.012	-0.013
	(0.033)	(0.030)	(0.028)	(0.025)
Mover/Exiter/Retiree Comparisons (p-values)				
H_0: Schl Chngr=Grd Chngr=Pre1=Pre2 =Pre3=Retained=Typical=Pushed Out	0.69	0.26	0.46	0.09
H_0: Retained=Typical=Pushed Out	0.66	0.74	0.90	0.54
Student Covariates	X	X	X	X
School Covariates	X		X	
School Fixed Effects		X		X
R-Squared	0.63	0.64	0.63	0.63
N	588,928	588,928	588,003	588,003

Notes: Standard errors are in parentheses and clustered at the school-by-grade-by-year level. The structure of the model in equation (3) is such that we can include one extra year-cohort of students in the dataset, which is why the sample sizes are larger in these models. We have also estimated analogous models using various partitions of the full dataset and we obtain similar results.

** Indicates statistical significance at the 1 percent level.

* Indicates statistical significance at the 5 percent level.

† Indicates statistical significance at the 10 percent level.

Appendix A
Pension-Wealth Calculations

Our pension-wealth calculations are for a representative female teacher in Missouri who was 37 years old in 2009 and began as a teacher at the age of 25. To calculate her pension wealth we use the following information: (1) age, (2) system experience and (3) earnings, or expected earnings, for the three years prior to exit.

We determine the representative teacher's survival probabilities over the life cycle using the Cohort Life Tables provided by the Social Security Administration. We project out future wages using a growth function that depends on teaching experience. The parameters of the growth function come from a regression based on an 18-year data panel from Missouri where we regress teacher wages on a cubic function of experience. The function captures real wage growth, and wages are also adjusted for inflation. The representative teacher in Figure 1 starts with the base wage typical of a 37-year-old teacher in Missouri, and the growth function adjusts the wage profile moving forward so that *FAS* can be calculated after each possible exit date.

Our PDV calculations also require that we specify a real discount rate. We use a real discount rate of 4 percent in our calculations, which allows for a positive real interest rate and some time preference in earnings.[27] Our calculations are sensitive to adjustments to the discount rate. For example, halving the real discount rate roughly doubles the peak-value of pension wealth in Figure 1. But substantively, our findings depend on the presence of the pension-wealth spikes, and the subsequent decline in pension-wealth late in the career cycle. As long as the true discount rate isn't so large as to negate the economic meaning of these features of the pension system, an accurate characterization of the actual discount rate is not important for our work.

[27] Our choice of a four-percent real discount rate falls somewhere in between what others have used in the literature. For example, Coile and Gruber (2007) use 6 percent, and Costrell and Podgursky (2009) use 2.5 percent.

For the representative teacher in Figure 1, after each year of work we identify the optimal collection age assuming that the teacher exits after that year, then calculate the PDV of the expected stream of pension payments over the life cycle. An individual's pension-wealth at time *s*, with collection starting at time *j*, where $j \geq s$, can be written as:

$$\sum_{t=j}^{T} Y_t * P_{t|s} * d^{t-s} \tag{A.1}$$

In (A.1), Y_t is the annual pension payment in period *t*, $P_{t|s}$ is the probability that the individual is alive in period *t* conditional on being alive in period *s*, and *d* is the discount factor.[28]

[28] In our calculations we set T = 101, although after accounting for the impact of discounting and the survival probabilities the calculations are qualitatively insensitive to reasonable adjustments to this threshold.

Appendix B
Supplementary Tables

Appendix Table B.1. Key Parameters of the Missouri Pension System, 1995 – 2009 (there were no changes after 2002). Initial Parameters as of 1995 are Reported in Row 1.

	PSRS
1995*	Formula factor 0.023, early retirement by 55-25 rule, COLA cap 65 percent
1996	Implement unrestricted "25 and out"
1997	COLA cap increased from 65 to 75 percent
1998	
1999	Formula factor raised to 0.025 for full retirement (with corresponding upward adjustments for early retirement)
2000	Implement Rule of 80, FAS changed to highest three years of salary
2001	COLA cap increased to 80 percent
2002	Formula factor increased to 0.0255 if YOS ≥ 31 (new factor applies to *all service years* for eligible individuals)

* Notes: The 55-25 rule is a more-restrictive version of the rule of 80. It requires a teacher to have at least 25 years of service and be at least 55 years old to retire.

Appendix Table B.2. Estimates for the Other Coefficients from Equation (2).

	Math	Reading
Lagged Score	0.728	0.713
	(0.002)**	(0.002)**
American Indian	-0.036	-0.003
	(0.013)**	(0.014)
Asian	0.133	0.101
	(0.008)**	(0.008)**
Black	-0.116	-0.094
	(0.004)**	(0.004)**
Hispanic	-0.021	-0.003
	(0.006)**	(0.006)
Female	-0.013	0.036
	(0.002)**	(0.002)
Free Lunch Eligible	-0.091	-0.098
	(0.002)**	(0.002)**
Special Education	-0.208	-0.236
	(0.004)**	(0.004)**
English as Second Language	-0.056	-0.070
	(0.009)**	(0.008)**
Mobile Student (in building less than one year)	-0.098	-0.088
	(0.005)**	(0.005)**
Student Covariates	X	X
School Covariates		
School Fixed Effects	X	X
N (student test-score records)	451,948	450,986

Notes: Standard errors are in parentheses and clustered at the school-by-grade-by-year level. These estimates are from the models shown in column (6) in Tables 3 and 4, but similar estimates are obtained in the other specifications. The school-fixed-effects models omit the time-varying school level controls. See text for details.
** Indicates statistical significance at the 1 percent level.
* Indicates statistical significance at the 5 percent level.
† Indicates statistical significance at the 10 percent level.

Appendix Table B.3. An Investigation of Classification Errors for Teacher Types Using Data for the 2006-2007 and 2007-2008 Cohorts Only.

Exit Classification	Exits Determined Using Personnel Data Through 2008-2009 Only	Exits Verified Using Personnel Data Through 2009-2010
Premature Exits 1 (PE_{isgt}^{t+1})	9.42%	8.67
Premature Exits 2 (PE_{isgt}^{t+1})	6.37	5.81
Premature Exits 3 (PE_{isgt}^{t+1})	5.45	4.88
Retained Teachers (RT_{isgt}^{t+1})	0.35	0.32
Typical Retirees (TR_{isgt}^{t+1})	1.84	1.80
Pushed-Out Teachers (PO_{isgt}^{t+1})	1.48	1.48

Notes: Estimates are from the 2006-2007 and 2007-2008 cohorts of teachers only.

Appendix Tables B.1 and B.2 are self explanatory. In Appendix Table B.3 we examine the extent to which there are likely to be misclassification errors in the teacher-type designations in our main dataset. A key concern is that teachers exit behaviors are coded based on whether they disappear from the data panel, but some teachers who disappear in the final year of the panel may return at a later time (teachers who disappear and return in earlier years are not miscoded, but for teachers who disappear in the last year we cannot observe their returns if they occur).

We investigate the extent to which this issue is likely to result in misclassification errors, and attenuation bias in our estimates, by focusing on the subsample of teachers who are observed teaching in the first two years of the achievement data panel: 2006-2007 and 2007-2008. First, we code the exit and retirement variables for teachers as if our achievement data panel ended after 2007-2008, using information only through 2008-2009 to determine who exited. This roughly replicates the conditions under which teachers in our main analysis are classified. Then we use an additional year of post-analysis data – 2009-2010 – to look for misclassification errors in the teacher categorizations. So, for example, if a teacher left in 2008-2009 as a premature exiter, but returned in

2009-2010, this would be a case where the teacher's type would be misclassified using the main classification system (e.g., she may not be a premature exiter – she may have simply taken a one-year leave).

Appendix Table B.3 shows the shares of teachers from the 2006-2007 and 2007-2008 school years who are classified into each exit category, with and without the extra year of data to confirm the exits.[29] The results are intuitive – younger teachers are more likely to move in and out of the workforce, and therefore there are more errors for these teacher types. However, there are few errors for the retiree groups – retirement-eligible teachers rarely leave and come back. We conclude that our primary findings for retirees are essentially unaffected by misclassification errors in the data.

[29] We do not worry about misclassifications in the other direction – that is, teachers who do not actually exit in 2008-2009 but do exit in 2009-2010. These teachers are included in the composite-average omitted group – of course, all of the teachers in the composite-average group will ultimately exit through one avenue or another. The key point for the purpose of our comparisons is that as a group, the non-exiters are broadly representative of the workforce.